

Longwave forcing uncertainties in climate models

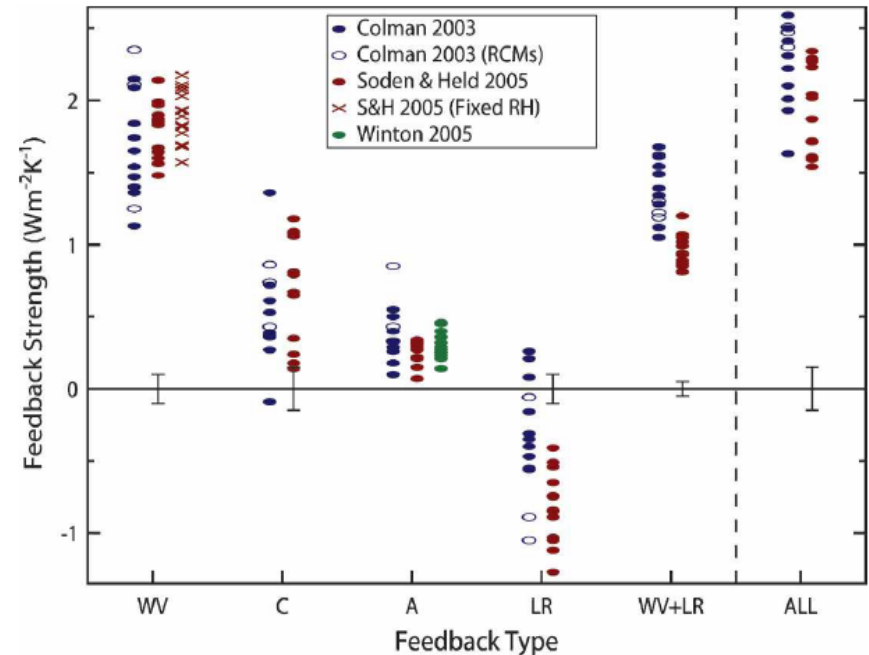
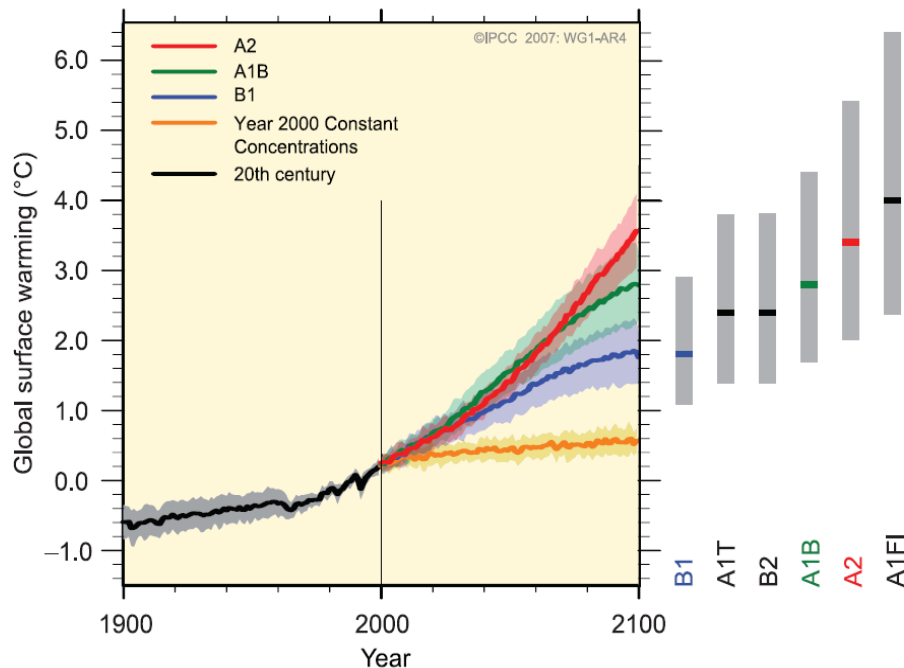
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Projection discrepancy ⇔ model sensitivity (feedback) difference

IPCC AR4

MULTI-MODEL AVERAGES AND ASSESSED RANGES FOR SURFACE WARMING



$$\Delta R = G + S^{-1}\Delta T \quad \dots (1)$$

$$S^{-1}\Delta T = \Sigma(\Delta R_x) \quad \dots (2)$$

$$\Delta R_x = (dR/dX) \Delta X \quad \dots (3)$$

(T: surf T; R: net rad; G: forcing; S: Sensitivity parameter; ΔR_x : feedback)

In each scenario experiment, forcing assumed to be the same across the models, so that:

ΔT diff. $\rightarrow S^{-1}$ diff. $\rightarrow \Delta R_x$ diff.

Issue: large unexplained ΔR residual

$$\Delta R = G + \Sigma(\Delta R_x) + \text{res}$$

Example: AR4 A1B experiment
2000-2050 period;

Forcing: $G=4.3 \text{ W m}^{-2}$
[IPCC TAR; Soden 2008]

Feedback:

Non-cloud: $\Delta R_x = (dR/dX) \Delta X$

Cloud: Cloud forcing adjustment

Outstanding issues - Res:

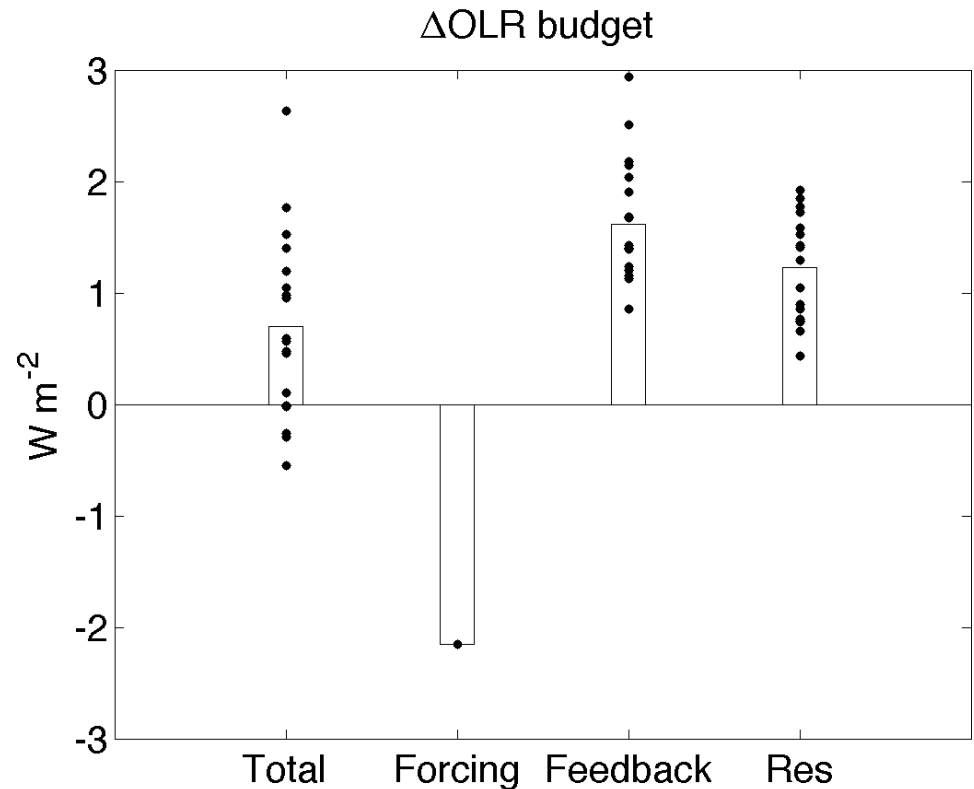
1) considerable magnitude

$\text{Res}/\Delta R \sim O(100\%)$

2) substantial inter-model spread;

2) Significant $\text{corr}(\text{res}, \Delta T_s)$

($r = 0.55$, 18 models)

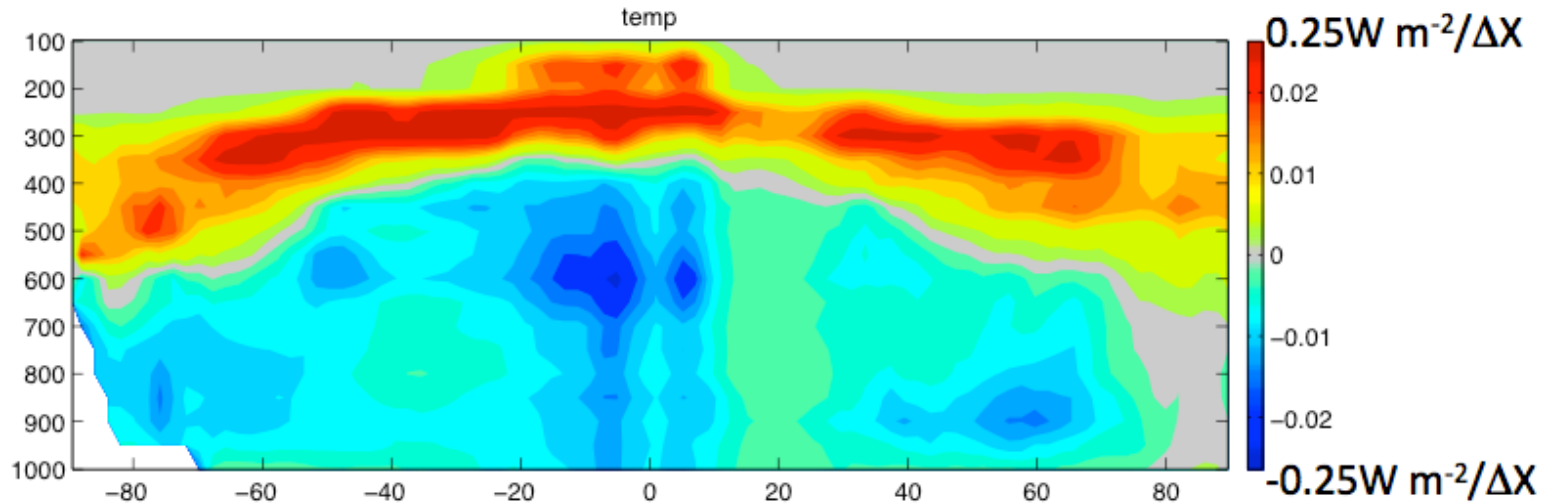


Huang 2013 J. Clim.

Cause: Kernel uncertainty?

dR/dT , dR/dq depend on base atmospheric state

Too much
cloud ice [Su et
al 2011]
=> Temp kernel
bias

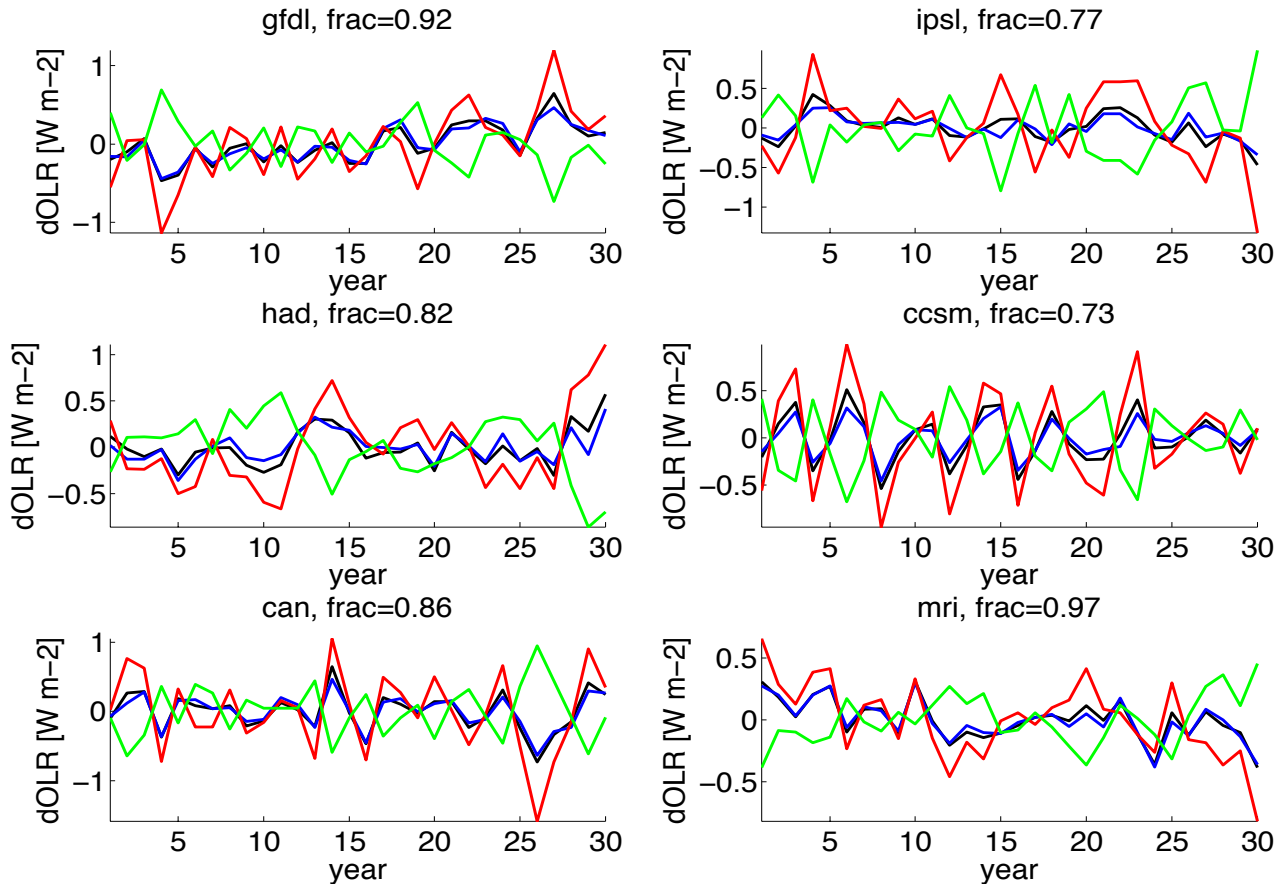


Multiple works indicate global/annu mean feedback uncertainty due to this uncertainty is small ($\leq 10\%$)

- Huang et al 2007: exam radiation code errors
- Soden et al 2008: comp kernels and feedbacks
- Sanderson and Shell 2012: kernel dependence on model atmosphere

Clear-sky ΔOLR breakdown

$$\Delta R^C = G^C + \Sigma(\Delta R^C_x) + Res^C$$



OLR decomp using a single set of kernels for multiple models in an unforced ($G=0$) experiment shows that ΔR^C_{res} , if caused by kernel uncertainty, would be small.

Black: model simulated global/annu mean clear-sky OLR anomaly;
Blue: reproduced by using kernels
Green: water vapor
Red: temperature

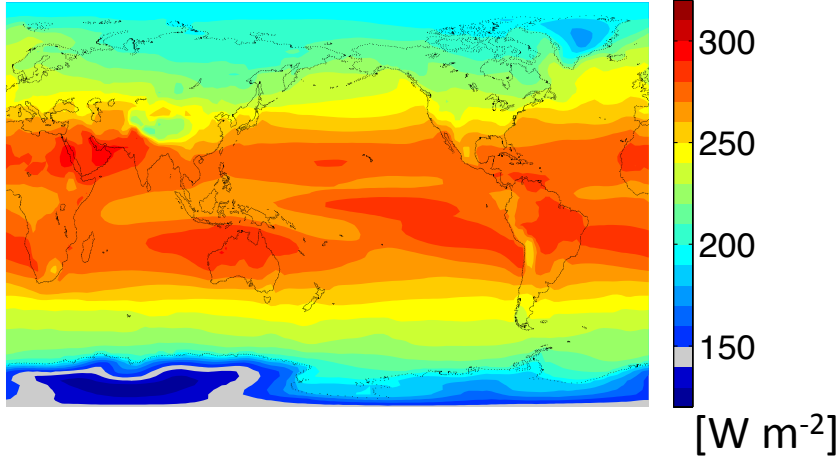
=> Forcing uncertainty is the major cause of Res!

Why G varies?

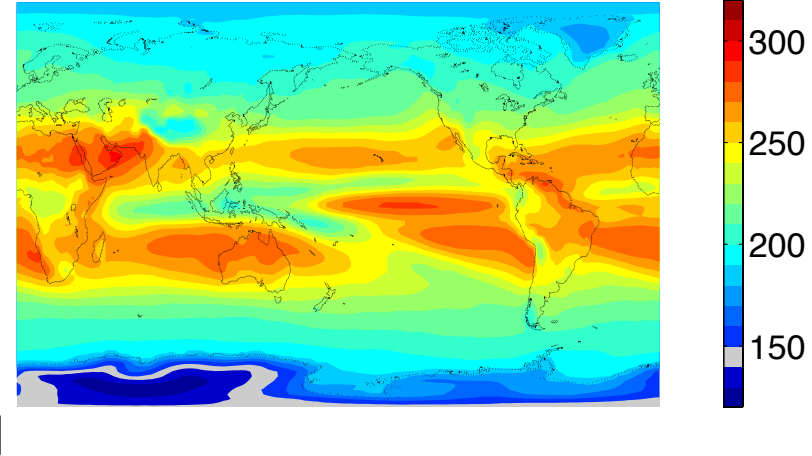
e.g., nxCO2 forcing calculated using PRP method

$$G = R(\gamma \times \text{GHG}, T, W, C, \dots) - R(\text{GHG}, T, W, C, \dots)$$

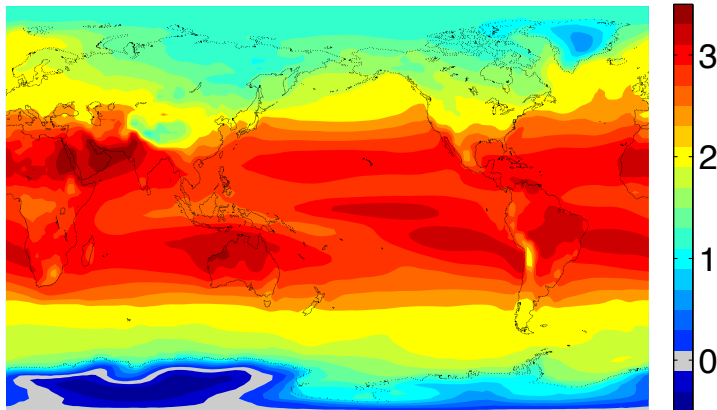
clear-sky OLR



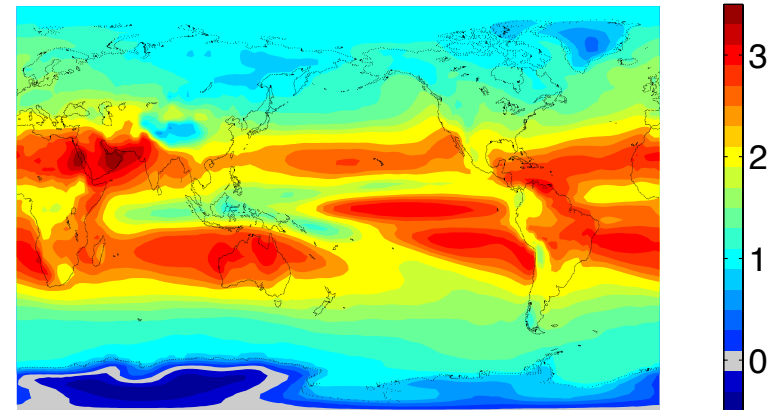
all-sky OLR



clear-sky 2xCO2 forcing



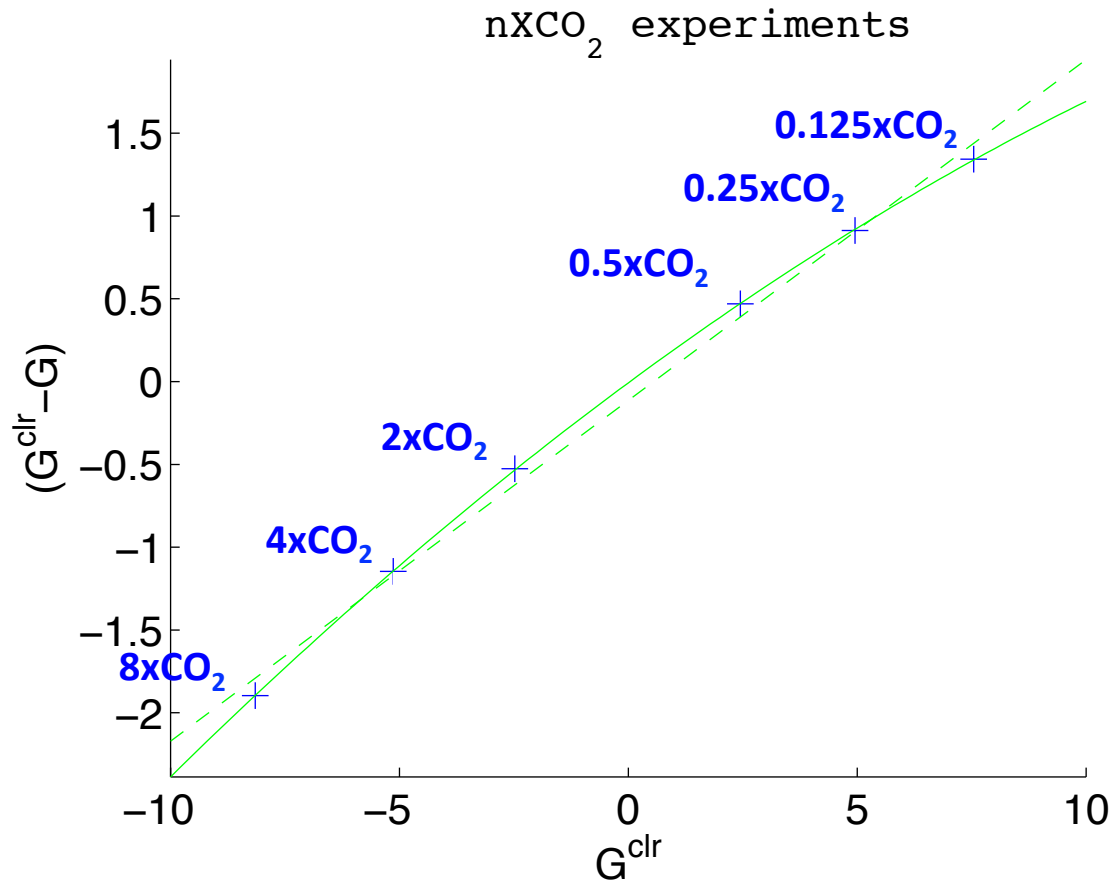
all-sky 2xCO2 forcing



multi-year
ave of 3hrly-
calculations

G is not
uniform –
depend
on other
atmos
cond!

G^{clr}/G relationship



- Soden et al 2008: $G^{\text{clr}}/G = 1.16$
- Verified by Vial et al 2013
- Here: verified by a series of nXCO₂ experiments

$(G^{\text{clr}} - G)$ can be predicted by G^{clr} !

How to estimate G?

- Available methods:
 - P.R.P. : much computation
 - Regression method [Gregory and Webb 2008]: not applicable when G varies

- A new proposal [Huang 2013]:
 - Basis: high linearity in clear-sky ΔOLR breakdown [Huang et al 2007; Huang et al 2010; Kato et al 2011; ...] :

$$G^C = \Delta R^C - \Sigma(\Delta R_x^C) - \text{Res}^C$$

small

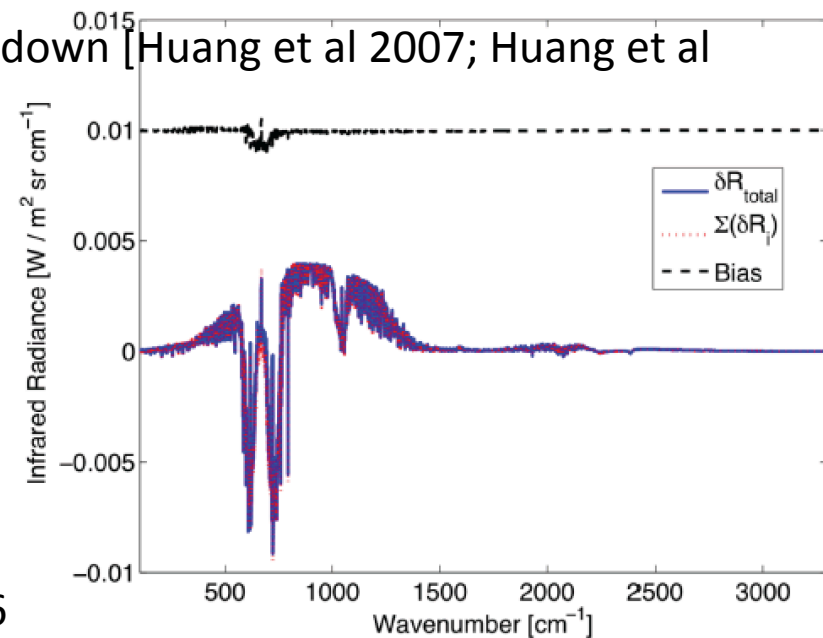
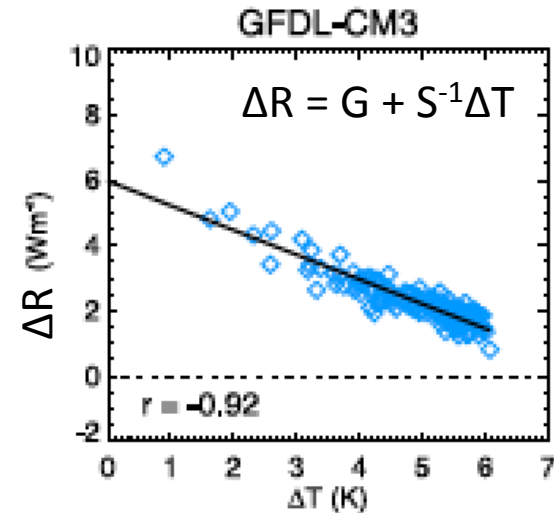
- Use kernels for non-cloud feedbacks:
Temp and w.v.

$$\Delta R_x = (\partial R / \partial X) dX; \quad X: T, WV$$

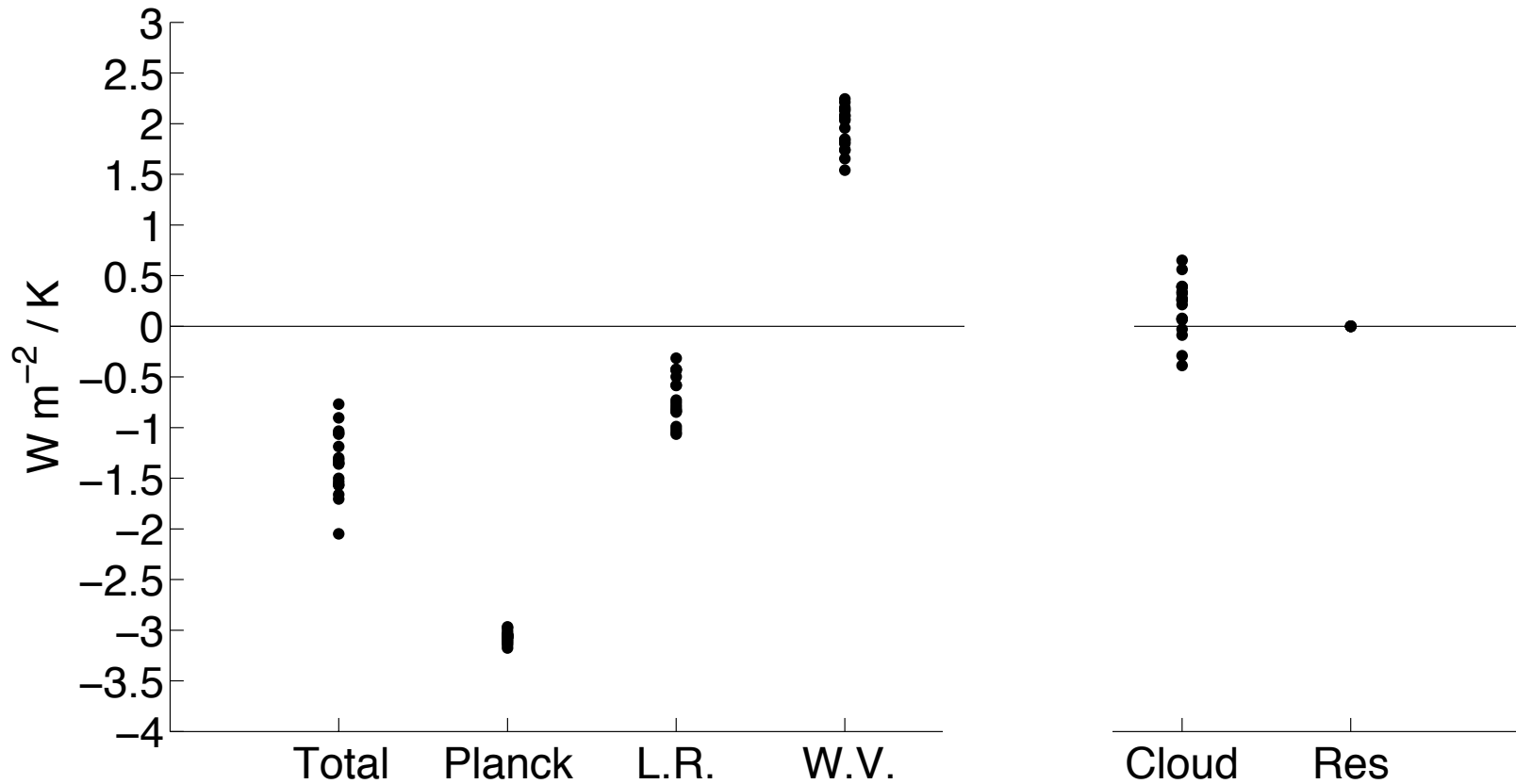
- Make use of an empirical G^C/G ratio :
Following Soden et al [2008]: $(G^C - G)/G = 0.16$

- Cloud Forcing Adjustment (CFA) method for cloud feedback:

$$\Delta R_{\text{cld}} = (\Delta R - \Delta R^C) - (G - G^C) + \Sigma(\Delta R_x - \Delta R_x^C)$$

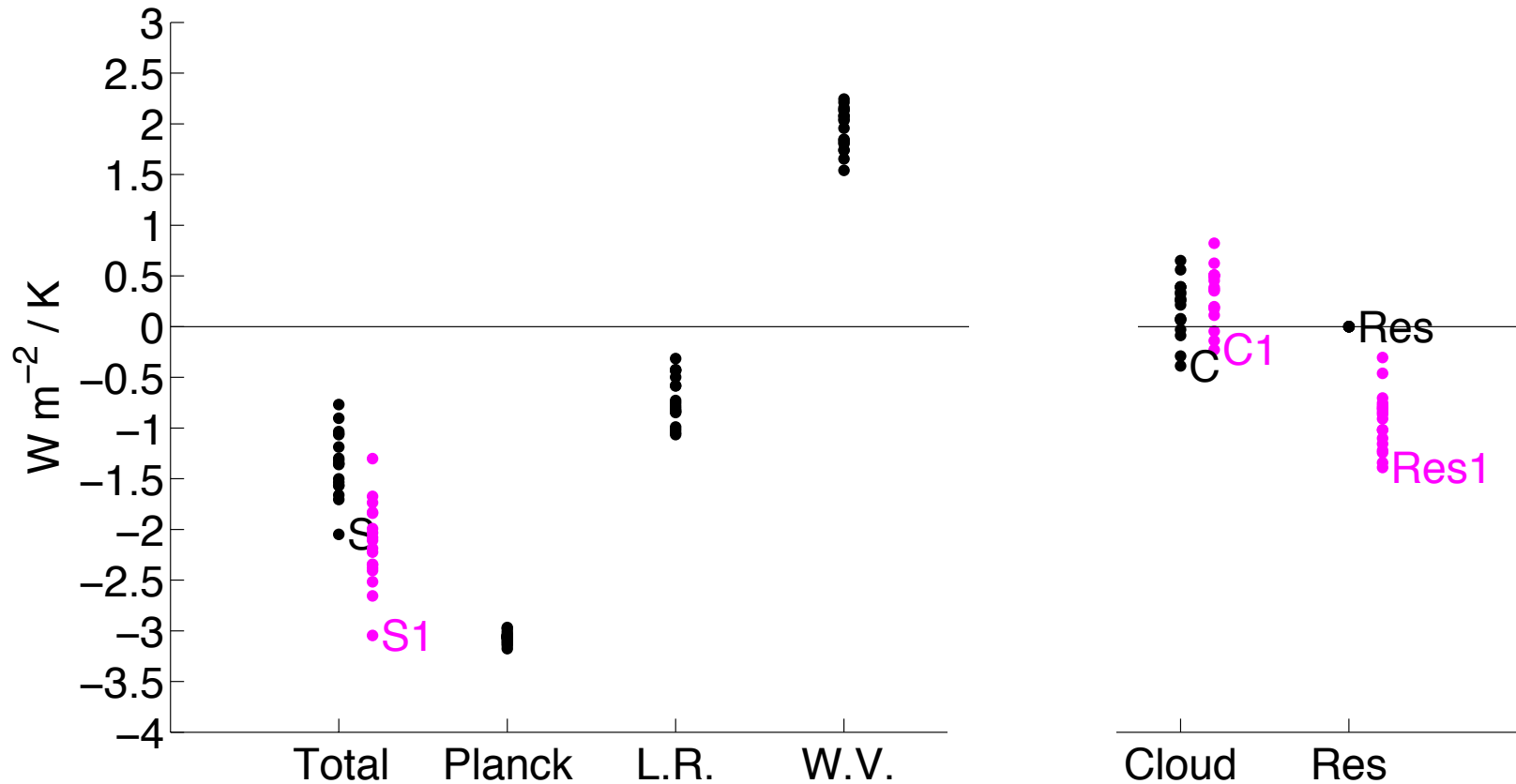


Results



Non-cld feedbacks	Huang 2013	Held&Shell 2012
Planck	-3.07 ± 0.05	-3.10 ± 0.04
Lapse Rate	-0.72 ± 0.24	-0.89 ± 0.27
Water Vapor	1.95 ± 0.21	1.98 ± 0.21

Results



S/C/Res: G estimated for each model

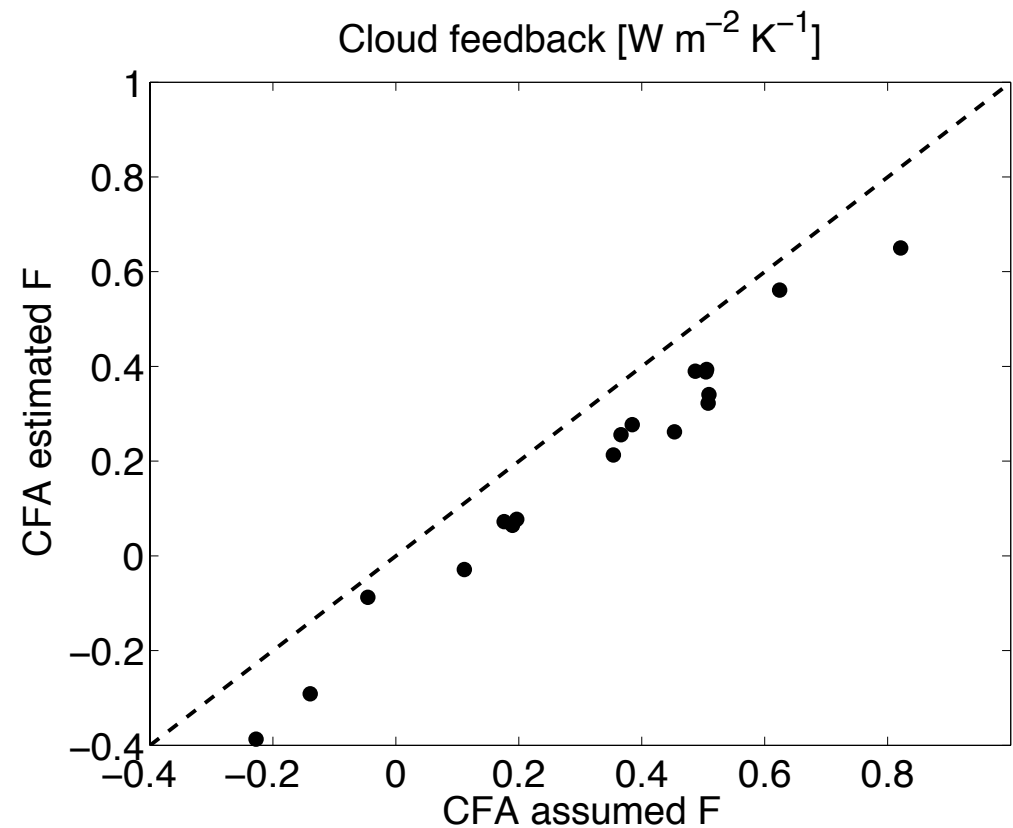
S1/C1/Res1: Assume a constant G

- S1 ($= (\Delta R - G) / \Delta T$) has a considerably larger spread
- C1 biased compared to C
- Res1: unexplained feedback component(s)

Impact on cloud feedback

$$\Delta R_{\text{cld}} = (\Delta R - \Delta R^{\text{C}}) - (G - G^{\text{C}}) + \Sigma(\Delta R_{\text{x}} - \Delta R_{\text{x}}^{\text{C}})$$

- ΔR_{cld} measured by the CFA method may be systematically biased if assuming an inaccurate constant G .
- For the A1B experiment, assuming $G = 4.3 \text{ W m}^{-2}$ leads to a noticeable overestimate of the LW cloud feedback.



JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, D16117, [doi:10.1029/2010JD013817](https://doi.org/10.1029/2010JD013817), 2010

Why is longwave cloud feedback positive?

Mark D. Zelinka¹ and Dennis L. Hartmann¹

Received 6 January 2010; revised 29 March 2010; accepted 29 April 2010; published 25 August 2010.

[1] Longwave cloud feedback is systematically positive and nearly the same magnitude across all global climate models used in the Intergovernmental Panel on Climate Change Fourth Assessment Report (AR4). Here it is shown that this robust positive longwave cloud feedback is caused in large part by the tendency for tropical high clouds to rise in such a way as to remain at nearly the same temperature as the climate warms. Furthermore,

How
positive is
LW cloud
feedback
really?

Summary

1. Even in scenario experiments when radiative species are identically prescribed, forcing (G) differs across different models;
2. G difference contributes to these models' climate projection discrepancy;
3. Cloud feedback, assessed by the CFA method (and as a residual term in general), may be biased due to G uncertainty;
4. A method is proposed for estimating G for each model in each experiment in feedback analysis;

Ref: Huang, 2013: On the longwave climate feedbacks, J. Clim., in press.

* CLARREO, e.g., via spectral fingerprinting, may especially help reduce forcing uncertainty.

Spectral fingerprinting of LW forcing and feedback

[Huang et al 2010]

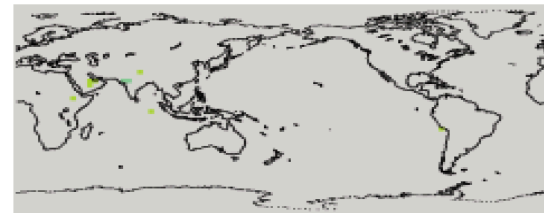
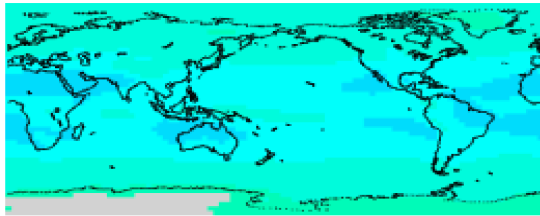
Truth

Fingerprinting bias

all-sky $\delta\text{OLR}_{\text{PRP}} \text{ CO}_2$

all-sky nEOF=50, $\delta\text{OLR}_{\text{OD}} \text{ Bias CO}_2$

10
5
0
-5
-10



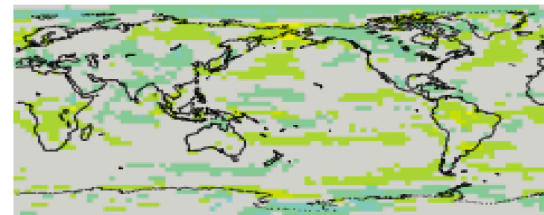
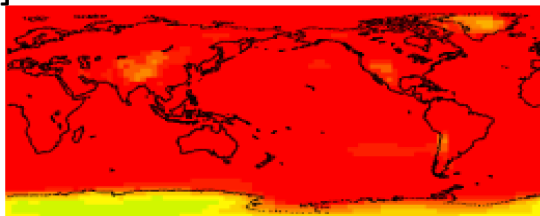
1
0.5
0
-0.5
-1

$\Delta R(\text{CO}_2)$

$\delta\text{OLR}_{\text{PRP}} \text{ ta-trop}$

$\delta\text{OLR}_{\text{OD}} \text{ Bias ta-trop}$

[W m⁻²]

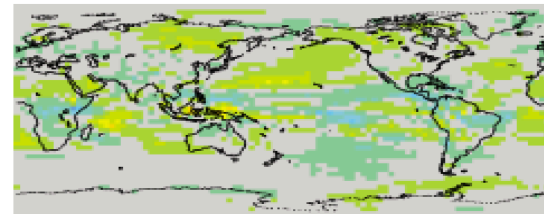
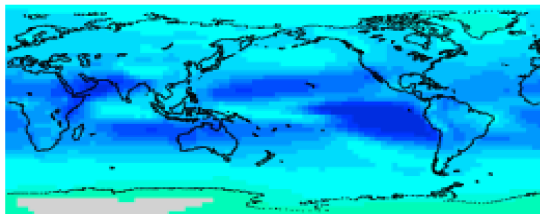


[W m⁻²]

$\Delta R(\text{Ta})$

$\delta\text{OLR}_{\text{PRP}} \text{ hus-trop}$

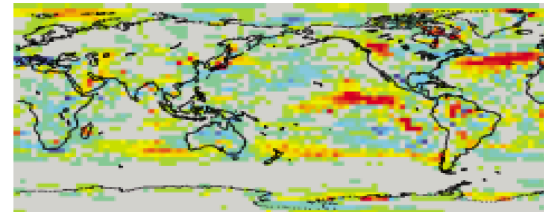
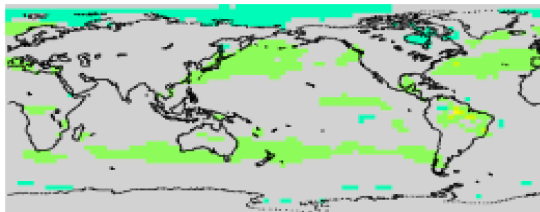
$\delta\text{OLR}_{\text{OD}} \text{ Bias hus-trop}$



$\Delta R(\text{WV})$

$\delta\text{OLR}_{\text{PRP}} \text{ cld-lowertrop}$

$\delta\text{OLR}_{\text{OD}} \text{ Bias cld-lowertrop}$



$\Delta R(\text{C}_{\text{low}})$